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Trees on K-12 School Campuses in Virginia

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ABSTRACT

Trees and saplings growing on K-12 school campuses were investigated in 105 school districts across Virginia. There were 2812 trees (>12.5 cm stem diameter at 1.4 m above ground level) inventoried across all campuses. The mean and median campus tree population was 27 and 18, respectively. Loblolly pine (*Pinus taeda* L.) was the most abundant species, accounting for 11% of all inventoried trees. Red maple (*Acer rubrum* L.) was the most frequently inventoried species, present on 44% of the campuses. Sapling (trees with 2.5-12.5 cm stem diameter at 1.4 m above ground level) populations were similar to tree populations. The mean and median campus sapling population was 23 and 13, respectively. Flowering dogwood (*Cornus florida* L.) and red maple were the most abundant sapling species, each accounting for about 10% of all inventoried saplings. Flowering dogwood, red maple, Bradford pear (*Pyrus calleryana* Decne. 'Bradford'), willow oak (*Quercus phellos* L.), and ornamental cherry (*Prunus* spp.) were the most frequently inventoried sapling species, each present on more than 25% of the campuses. Across all campuses, species diversity was relatively low: less than 10 species accounted for over 50% of the inventoried trees and saplings. Prominent Virginia natives, in particular *Carya* and *Quercus* species, were under represented in the inventory.

INTRODUCTION

Urban forests are increasingly recognized for their ecological and societal benefits (Kane and Kirwan 2005). Trees in the urban forest improve air quality, protect watersheds, sequester carbon, and reduce energy consumption for heating and cooling buildings. In addition, properly designed and maintained urban vegetation has been linked to reduced crime (Kuo and Sullivan 2001), enhance cognitive development of children (Wells 2000), and job satisfaction (Kaplan *et al.* 1988).

As the U.S. population grows and becomes more urbanized, urban forests will play an increasingly important role in environmental sustainability and quality of life. From 1910 to 2000, the urban segment of the U.S. population increased from 28% to 80% (Hobbs and Stoops 2002). By 2030, 87% of the U.S. population (projected to exceed 370 million) will live in urbanized areas (UNESA 2004). The population of Virginia (currently about 7.5 million) is projected to reach 9.8 million by 2030 (U.S. Census Bureau 2005). In the Chesapeake Bay watershed alone, residential development is projected to consume 800,000 acres of land between 2003 and 2030 (Boesch and Greer 2003). This pattern and rate of population growth will place unprecedented strain on natural resources. Healthy, well-managed urban forests may be a key component of sustainable community growth.

In 1998, the Virginia Tech Department of Forestry began an outreach program to teach dendrology, forest biology, and forest management concepts to K-12 students and

other public audiences. The program was initiated to help address a nationwide decline in science achievement during the middle school years (Calsyn *et al.* 1999) and to help Virginia teachers meet their Standards of Learning (SOL) objectives (Board of Education 2003). The program has been delivered through a dedicated web site (http://www.cnr.vt.edu/dendro/forsite/contents.htm), classroom presentations by Virginia Tech undergraduate students, and internet-based scientific investigations conducted by K-12 students (Kirwan and Seiler 2005). Now in its eighth year, the outreach program has spanned across three states and reached nearly 15,000 K-12 students at 83 schools and numerous 4-H clubs.

As part of the outreach program, tree inventories were conducted on school campuses. From these inventories, school tree lists were compiled and placed on the program website. Dendrology fact sheets and an online dichotomous key developed by the Virginia Tech Department of Forestry were linked to the tree lists to facilitate student learning about tree identification and forest biology.

In compiling the tree lists, a wealth of information has emerged on the composition of campus tree populations. Trees are a valuable asset on school campuses. They not only provide important environmental benefits such as shade and storm water abatement, but are also a valuable, yet often overlooked, resource to teach students about ecology and stewardship. Perhaps more important, the composition of campus tree populations is arguably a reflection of local knowledge, attitudes, and values regarding trees on public property. In most localities, the same biological, socio-political, and economic forces that influence tree preservation and planting on school campuses similarly impact other public properties. For these reasons, campus tree inventories can provide insight into natural resource management and education efforts in Virginia. The purpose of this paper is to report key findings from these campus tree inventories and discuss the implications for future management and education efforts.

MATERIALS AND METHODS

From 2000 to 2005, the lead author, with assistance from local students, teachers, and extension agents, conducted tree inventories on K-12 school campuses across Virginia. Tree inventories were conducted at schools where outreach educational programs were conducted or where there was a request to compile a school tree list. To obtain a broad geographical representation, inventory data from only one school campus in each of 105 school districts were analyzed in this study (Appendix 1). In school districts where more than one campus was inventoried, the school that was first in alphabetical order was selected for this study. The majority of tree inventory data used in this study was collected at public elementary schools (91 of 105 campuses). The balance came from middle school (10), high school (1), or combined (2) campuses. One private elementary school campus was also inventoried.

The inventories were limited to trees growing in maintained campus areas. Boundary line trees and trees in campus natural areas were not inventoried. The species and stem diameter at breast height (DBH-measured 1.4 m above ground level) were determined for each inventoried tree. For multi-stemmed trees that divided below 1.4 m, the individual stem diameters were summed. Trees $\leq$ 12.5 cm DBH were designated as saplings in the inventory. Trees $<$2.5 cm DBH were not inventoried.

Species abundance, frequency, and importance metrics were calculated using the

TABLE 1. Statistics describing tree (>12.5 cm stem diameter at 1.4 m above ground level) and sapling (trees with 2.5-12.5 cm stem diameter at 1.4 m above ground level) populations inventoried on 105 Virginia school campuses during 2000-2005.

	Campus Plant Count	Campus Species Richness
Trees		
Minimum	0	0
25th Percentile	8	3
Median	18	6
Mean	27	7
75th Percentile	39	9
Maximum	162	23
Total	2812	100
Saplings		
Minimum	0	0
25th Percentile	6	3
Median	13	5
Mean	23	6
75th Percentile	25	8
Maximum	196	22
Total	2431	103

combined inventory data. Each metric was calculated separately for trees and saplings. Species abundance was calculated as the number of plants of a given species divided by the total number of plants in the inventory. Species frequency was calculated as the number of campuses where a species was inventoried divided by the total number of campuses inventoried. Abundance and frequency values were multiplied by 100 and expressed as percentages.

Species importance was calculated as the sum of the abundance and frequency percentages. The importance metric was developed as a simple way to communicate both the preponderance and geographic distribution of a species. A high importance value does not necessarily imply that a species has high ecological or economic value. Rather, the importance metric reveals patterns in tree preservation and tree planting on school campuses that are not discernable from the abundance and frequency metrics alone.

RESULTS

Trees

There were 2812 trees inventoried across the 105 school campuses (Table 1). The mean and median campus tree population was 27 and 18, respectively. Three campuses each had over 100 inventoried trees (Figure 1). Conversely, nine campuses had no inventoried trees. About one-fourth of the campuses had eight or fewer inventoried trees.

There were 100 tree species, representing 52 genera, inventoried across the 105 school campuses. On average, there were seven different species on each campus.

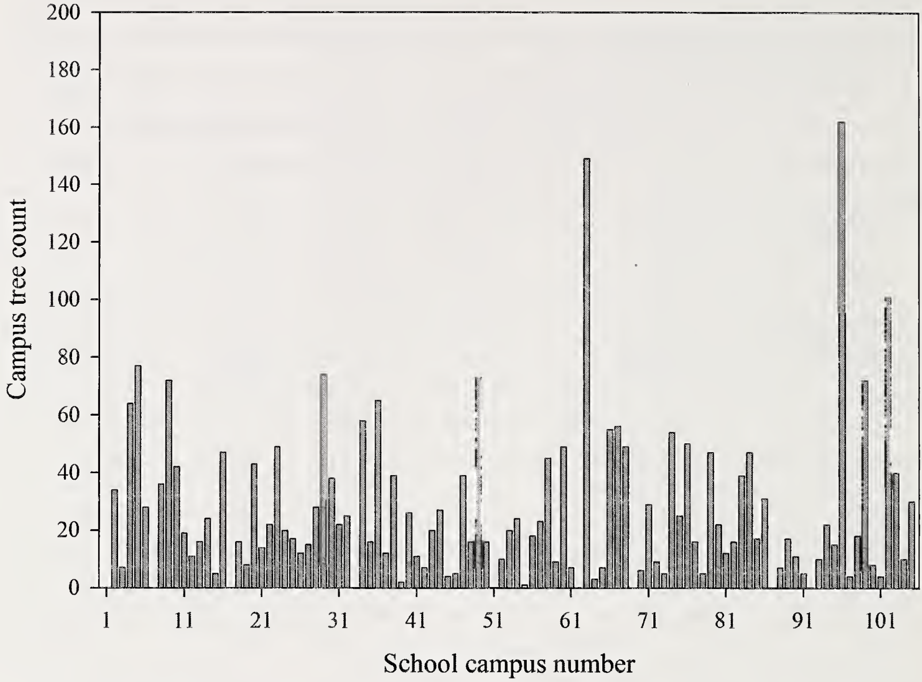

FIGURE 1. Total number of trees (>12.5 cm stem diameter at 1.4 m above ground level) inventoried on each of 105 Virginia school campuses during 2000-2005. Refer to appendix 1 for a complete list of school districts and names.

Two campuses were notable for having over 20 species (Figure 2). About one-fourth of the campuses had three or fewer species.

Loblolly pine (*Pinus taeda* L.) was the most abundant tree species in the inventory, accounting for 11% of the total tree population (Table 2). Loblolly pine, white pine (*Pinus strobus* L.), red maple (*Acer rubrum* L.), and Bradford pear (*Pyrus calleryana* Decne. 'Bradford') combined to account for 33% of the total tree population. The most frequently inventoried tree species was red maple, which was present on 44% of the campuses. Other common species were Bradford pear, flowering dogwood (*Cornus florida* L.), white pine, willow oak (*Quercus phellos* L.), and pin oak (*Quercus palustris* Muenchh.). Each of these species was present on about 30% of the campuses. Several tree species that are common in Virginia's native forests were scarce on school campuses. Pignut hickory (*Carya glabra* (Mill.) Sweet), American beech (*Fagus grandifolia* Ehrh.), blackgum (*Nyssa sylvatica* Marsh.), and black oak (*Quercus velutina* Lam.) were each present on less than 10% of the campuses.

Red maple had the highest importance value of all inventoried tree species, despite the fact that it accounted for only 7% of the total tree population (Table 2). Red maple's high importance value was strongly influenced by its occurrence on nearly half of the campuses. Other species with high importance values were Bradford pear, white pine, and flowering dogwood. Like red maple, these species were very common on school campuses.

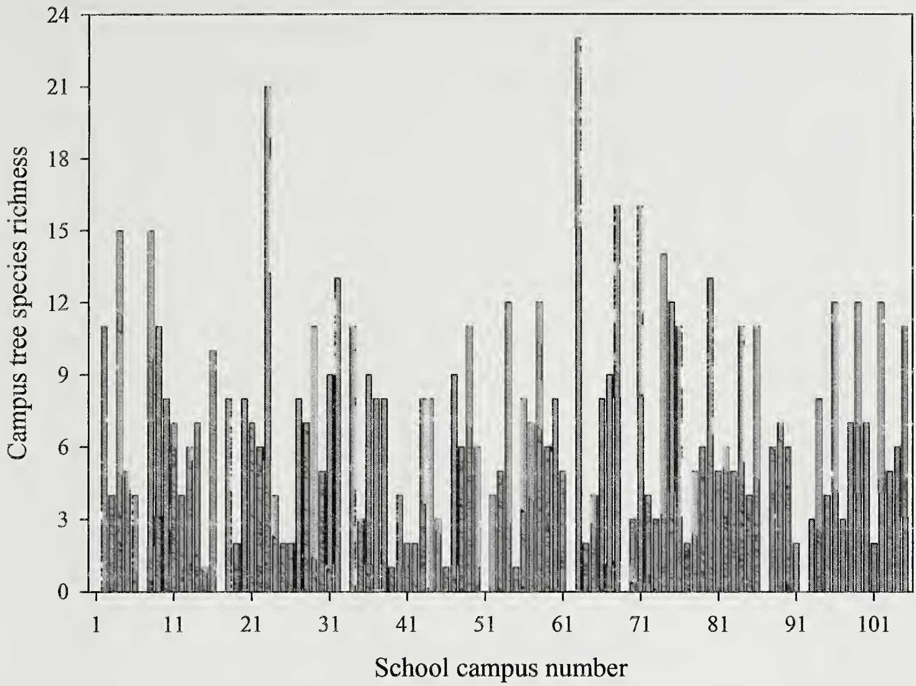

FIGURE 2. Total number of tree (>12.5 cm stem diameter at 1.4 m above ground level) species inventoried on each of 105 Virginia school campuses during 2000-2005. Refer to appendix 1 for a complete list of school districts and names.

Saplings

The tree and sapling populations were similar. There were 2431 saplings inventoried across the 105 school campuses (Table 1). The mean and median campus sapling population was 23 and 13, respectively. One campus had nearly 200 inventoried saplings whereas six campuses had none (Figure 3). About one-fourth of the campuses had six or fewer inventoried saplings.

There were 103 sapling species, representing 55 genera, inventoried across the 105 school campuses. Similar to the tree population, there was an average of six sapling species on each campus. The maximum number of sapling species on a single campus was 22 (Figure 4). About one-fourth of the campuses had three or fewer species.

Flowering dogwood and red maple were the most abundant sapling species, each accounting for about 10% of the total sapling population (Table 3). Eight species accounted for 50% of the total sapling population. The most frequently inventoried sapling species was flowering dogwood, which was present on more than half of the campuses. Other common species were red maple, Bradford pear, willow oak, and ornamental cherry (*Prunus* spp.). Each of these species was present on more than 25% of the campuses.

As was observed for the trees, saplings of native forest species were uncommon on school campuses. The widespread Virginia natives, red mulberry (*Morus rubra* L.),

TABLE 2. Trees (>12.5 cm stem diameter at 1.4 m above ground level) inventoried on 105 Virginia school campuses during 2000-2005. Only species with an importance value greater than five are individually listed.

Species	Count	Abundance (%)[a]	Presence[b]	Frequency (%)[c]	Importance[d]
Acer rubrum	198	7	46	44	51
Pyrus calleryana	190	7	35	33	40
Pinus strobus	250	9	32	30	39
Cornus florida	107	4	35	33	37
Pinus taeda	301	11	24	23	34
Quercus phellos	138	5	29	28	33
Quercus palustris	84	3	29	28	31
Acer saccharum	115	4	26	25	29
Liquidambar styraciflua	97	3	24	23	26
Prunus serotina	43	2	22	21	22
Quercus alba	122	4	19	18	22
Quercus falcata	48	2	20	19	21
Juniperus virginiana	52	2	19	18	20
Platanus occidentalis	46	2	13	12	14
Acer saccharinum	39	1	12	11	13
Robinia pseudoacacia	55	2	11	10	12
Magnolia grandiflora	23	1	12	11	12
Ilex opaca	37	1	11	10	12
Fraxinus americana	32	1	10	10	11
Liriodendron tulipifera	38	1	9	9	10
Acer platanoides	34	1	9	9	10
Prunus spp. (ornate cherry)	25	1	9	9	9
Picea abies	19	1	9	9	9
Malus spp. (crab apple)	14	<1	9	9	9
Pinus virginiana	24	1	8	8	8
Celtis occidentalis	38	1	7	7	8
X *Cupressocyparis leylandii*	60	2	6	6	8
Juglans nigra	32	1	7	7	8
Gleditsia triacanthos	40	1	6	6	7
Prunus cerasifera	9	<1	7	7	7
Quercus nigra	17	1	6	6	6
Quercus velutina	13	<1	6	6	6
Carya tomentosa	12	<1	6	6	6
Cercis canadensis	12	<1	6	6	6
Nyssa sylvatica	10	<1	6	6	6
Malus spp. (common apple)	22	1	5	5	6
All other species	416	15	-	-	-

[a]Percentage of the total tree inventory accounted for by the listed species.
[b]Number of campus where the species was inventoried.
[d]Percentage of all campuses where the species was inventoried.
[d]Abundance (%) + Frequency (%)

serviceberry (*Amelanchier* spp.), common persimmon (*Diospyros virginiana* L.), and Virginia pine (*Pinus virginiana* P. Mill.), were each present on less than 5% of the campuses. With the exception of willow and pin oak, saplings of the native oak and hickory species were extremely uncommon (each less than 3% frequency).

Flowering dogwood had the highest importance value among inventoried saplings

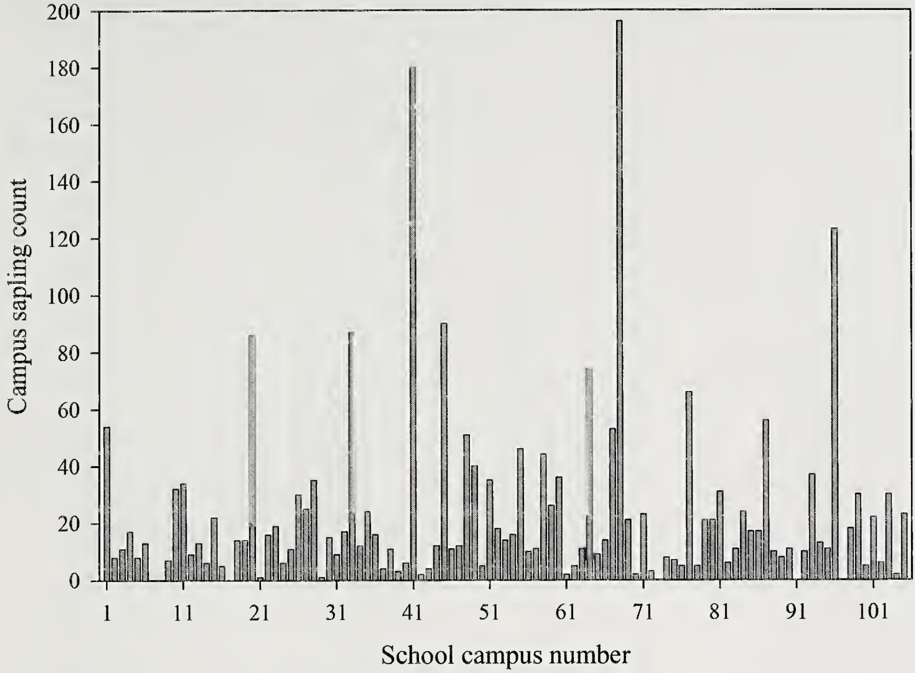

FIGURE 3. Total number of saplings (trees with 2.5-12.5 cm stem diameter at 1.4 m above ground level) inventoried on each of 105 Virginia school campuses during 2000-2005. Refer to appendix 1 for a complete list of school districts and names.

due to its widespread occurrence on campuses. Other highly important sapling species included red maple, Bradford pear, willow oak, and ornamental cherry. Like flowering dogwood, these species also had a wide geographic distribution.

DISCUSSION

The results of this study indicate there is substantial variability in the size and diversity of tree populations on Virginia K-12 school campuses. Although tree and sapling count data were not adjusted for campus acreage, the data raise concern for inadequate tree populations on school campuses. Particularly alarming was the fact that one-fourth of the schools inventoried had less than nine trees and seven saplings. While some of these schools may be located on small or highly urbanized parcels that preclude large tree populations, additional social and economic constraints are likely involved. Specifically, limited public interest and understanding about trees combined with strained municipal budgets may be leading to poor tree preservation, planting, and maintenance efforts on school campuses.

Age diversity in the tree population is a fundamental principle of urban forestry. Low age diversity threatens urban forest stability when there are inadequate numbers of young trees to replace mature trees as they die (Richards 1983). In this study, saplings, on average, accounted for 44% of the total tree population on individual campuses (data not shown). Interestingly, this demographic is consistent with

TABLE 3. Saplings (trees with 2.5-12.5 cm stem diameter at 1.4 m above ground level) inventoried on 105 Virginia school campuses during 2000-2005. Only species with an importance value greater than five are individually listed.

Species	Count	Abundance (%)[a]	Presence[b]	Frequency (%)[c]	Importance[d]
Cornus florida	240	10	62	59	69
Acer rubrum	214	9	38	36	45
Pyrus calleryana	132	5	35	33	39
Quercus phellos	117	5	26	25	30
Prunus spp. (ornate cherry)	110	5	26	25	29
Pinus strobus	139	6	17	16	22
Ilex cornuta	136	6	16	15	21
Malus spp. (crab apple)	36	1	18	17	19
X *Cupressocyparis leylandii*	92	4	14	13	17
Cercis canadensis	31	1	16	15	17
Prunus cerasifera	56	2	14	13	16
Quercus palustris	43	2	14	13	15
Platanus occidentalis	31	1	13	12	14
Pinus taeda	152	6	7	7	13
Juniperus virginiana	32	1	12	11	13
Ilex x *attenuata*	53	2	11	10	13
Ilex opaca	49	2	11	10	12
Acer saccharum	70	3	9	9	11
Thuja occidentalis	80	3	8	8	11
Fraxinus pennsylvanica	48	2	8	8	10
Betula nigra	21	1	9	9	9
Prunus subhirtella	9	<1	9	9	9
Cornus kousa	19	1	8	8	8
Zelkova serrata	25	1	7	7	8
Liquidambar styraciflua	16	1	7	7	7
Magnolia grandiflora	16	1	7	7	7
Unknown species	16	1	7	7	7
Acer saccharinum	7	<1	7	7	7
Sassafras albidum	13	1	6	6	6
Gleditsia triacanthos	35	1	5	5	6
Liriodendron tulipifera	11	<1	6	6	6
Prunus serotina	8	<1	6	6	6
All other species	374	15	-	-	-

[a]Percentage of the total tree inventory accounted for by the listed species.
[b]Number of campus where the species was inventoried.
[d]Percentage of all campuses where the species was inventoried.
[d]Abundance (%) + Frequency (%)

Richard's commonly implemented age diversity model, which recommends that 40% of an urban tree population consist of trees <20 cm DBH. However, a number of schools are at risk of low tree populations in the future. About one-fifth of the inventoried schools have less than half the number of saplings required by Richard's benchmark (data not shown).

Overall species diversity observed on school campuses was substantial. More than 100 species of trees and saplings were documented across the state. However, the over-abundance of some species is cause for concern. Seven species accounted for nearly

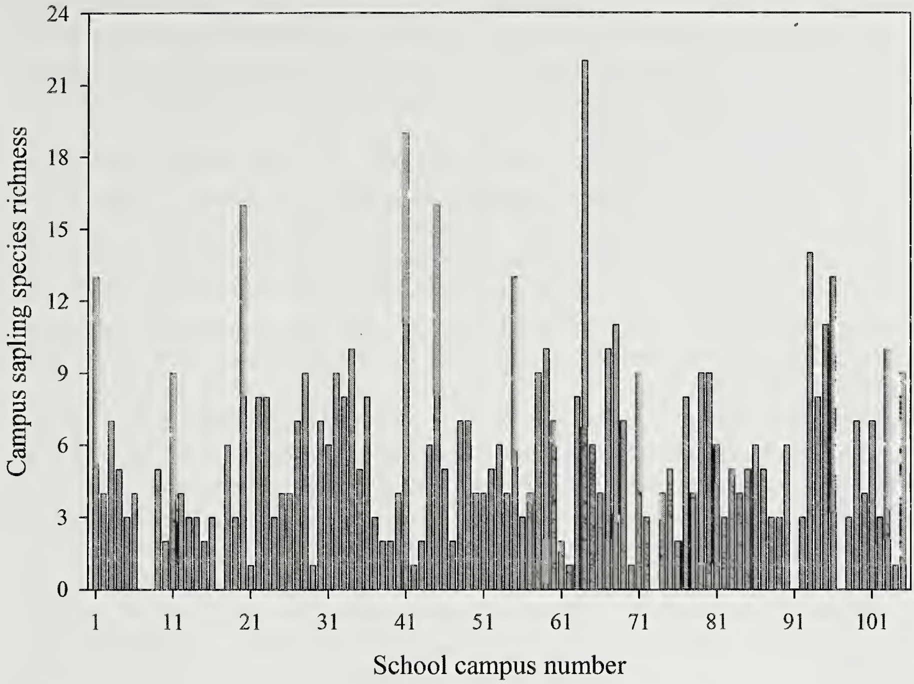

FIGURE 4. Total number of sapling (trees with 2.5-12.5 cm stem diameter at 1.4 m above ground level) species inventoried on each of 105 Virginia school campuses during 2000-2005. Refer to appendix 1 for a complete list of school districts and names.

half of the inventoried trees and saplings, which indicates campus landscapes are reliant on too few species. Urban forest stability is threatened when taxon-specific pests or disorders arise in tree populations dominated by a few species (Richards 1983). In such cases, a dramatic decline in the tree population can quickly occur as trees succumb to the emerging threat. The economic, social, and environmental implications can be severe.

In the U.S., a number of urban forest catastrophes resulting from taxon-specific problems have occurred. During the early 20th century, American elms (*Ulmus americana* L.) were decimated by Dutch elm disease, caused by the fungus *Ophiostoma ulmi* (Buism.) Nannf. (Nannini *et al.* 1998). At present, native ash species (*Fraxinus* spp.) are being extirpated by Emerald ash borer (*Agrilus planipennis* Fairmaire) throughout the upper Midwest (USDA 2006). To prevent such catastrophes, scrupulous municipalities often follow Santamour's species diversity model, which states that urban forests should be composed of no more than 10% of any single species, 20% of any single genus, and 30% of any single family (Galvin 1999).

Across the state, only loblolly pine exceeded the 10% species composition benchmark for trees; however, this demographic is misleading because over half of the loblolly pines were inventoried on just two campuses. While loblolly pine is clearly over-abundant on these two campuses, it is not a state-wide concern. Only the genus

Pinus exceeded the 20% genera benchmark, but *Acer* (14%) and *Quercus* (18%) were heavily planted on campuses as well. The family benchmark was not exceeded, although Pinaceae (24%) and Fagaceae (18%) were well represented across the state. Clearly, outreach efforts are needed to encourage greater tree species diversity on Virginia school campuses.

In the sapling population, taxonomic demographics were more diverse than in the tree population. This is likely due to the greater diversity of small-stature, ornamental species available in the nursery trade and the tendency for larger size classes to be dominated by a few long-lived, highly adaptable species (Richards 1983). Flowering dogwood accounted for 10% of the inventoried saplings, which was the only diversity benchmark exceeded in the sapling population. The abundance and frequency of flowering dogwood was not surprising because it is the state flower of Virginia and is a popular landscape tree.

The lower abundance of Bradford pear in the sapling population is encouraging and may reflect its declining popularity as a landscape tree due to its propensity for storm damage. The abundance and frequency of red maple in the sapling population may be cause for concern though. Red maple is a very popular landscape tree because it is attractive, easily propagated, and highly adaptable to diverse urban environments. However, these characteristics often lead to species over-use, and many urban foresters believe that red maple may be the next U.S. urban forest catastrophe. In one Maryland municipality, red maple accounted for over one-third of the entire urban forest population (Galvin 1999). Red maple use should be tempered on Virginia school campuses.

Only one of the ten most important tree species, Bradford pear, was not a Virginia native. Interestingly, this list is a close reflection of the ten most common trees in Virginia's native forests: white oaks, red oaks, yellow pines, yellow-poplar (*Liriodendron tulipifera* L.), maples, hickories, sweetgum (*Liquidambar styraciflua* L.), white pine, American beech (*Fagus grandifolia* Ehrh.), and blackgum (*Nyssa sylvatica* Marsh.) (VDEQ 2005). Some of the native species may be under represented on campuses because they are not readily available in commerce. For example, in 2005, only one nursery wholesaled American beech and none wholesaled hickories in Virginia (VNLA 2005). This is understandable because these two species are difficult to propagate and are often undesirable as landscape trees. However, white oaks, yellow-poplar, and blackgum are highly suitable for landscape use (Appleton and Chaplin 2001) and are increasingly available in commerce (VNLA 2005). These species should be better utilized on Virginia school campuses.

Non-native species were much more important within the sapling population. Five of the ten most important sapling species were non-native. Most of these species were small-stature ornamentals, which is a segment of the nursery trade dominated by introduced species. With the possible exception of Bradford pear, the non-natives species in the sapling population are dependable urban landscape plants.

Tree planting projects have played an important role in campus greening and youth education in Virginia for many years. The Virginia Department of Forestry (DOF) has been distributing seedlings to schools and civic groups since 1952 (Bart Bartholomew, Virginia Department of Forestry, Charlottesville, VA, personal communication). Loblolly pine and white pine, which are DOF nursery-grown species, were among the

most abundant and common species on school campuses. Current DOF efforts to expand native hardwood species production should positively affect campus species diversity if a means of low-cost distribution can be implemented.

This research has provided insight into the abundance and diversity of landscape trees on Virginia K-12 school campuses. The most alarming observation was the number of schools with very small tree populations. Inadequate tree populations are often the result of poor tree preservation, tree planting, or tree maintenance efforts. While the specific causes were not identified in this study, it is important to consider the consequences of inadequate campus tree populations. First, campuses do not fully benefit from the environmental services provided by trees such as storm water abatement and energy conservation. Second, the opportunity to demonstrate the fundamental concepts of urban forest stewardship to children is missed. Building awareness and advocacy in children is particularly important because they will make choices in their adult lives that impact future urban forests and thus long-term environmental sustainability. Preventing these consequences requires educating school administrators, local politicians, and the public about urban forestry and emerging urban forest issues.

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APPENDIX 1: Virginia school campuses where tree inventories were conducted during 2000-2005.

Number	District	School	Number	District	School
1	Accomack	Metompkin[a]	37	Gloucester	Achilles
2	Albemarle	Hollymead	38	Goochland	Rbt. Harford
3	Alexandria	Lyles-Crouch	39	Grayson	Baywood
4	Alleghany	Sharon	40	Greene	Greene Co.
5	Amelia	Amelia	41	Greensville	Greensville
6	Amherst	Amelon	42	Halifax	Scottsburg
7	Appomattox	Appomattox	43	Hampton	Armstrong
8	Arlington	H-B Woodlawn MS[b]	44	Hanover	Battlefield Park
9	Augusta	Beverley Manor	45	Henrico	Echo Lake
10	Bath	Valley	46	Henry	Axton
11	Bedford	Boonsboro	47	Highland	Highland
12	Bland	Bland EMHS[c]	48	Isle of Wight	Carrsville
13	Botetourt	Colonial	49	James City	Norge
14	Brunswick	Totaro	50	King & Queen	King & Queen
15	Buchanan	Russell Prater	51	King George	Sealston
16	Buckingham	Dillwyn	52	King William	Acquinton
17	Campbell	Rustburg	53	Lancaster	Lancaster MS
18	Caroline	Bowling Green	54	Lee	Jonesville MS
19	Carroll	Gladesboro	55	Loudoun	Ball's Bluff
20	Charles City	Charles City Co. MHS[d]	56	Louisa	Th. Jeffereson
21	Charlotte	Bacon District	57	Lunenburg	Victoria
22	Chesapeake	B.M. Williams	58	Lynchburg	Sheffield
23	Clarke	Powhatan[e]	59	Madison	Waverly Yowell
24	Craig	McCleary	60	Mathews	Lee-Jackson
25	Culpeper	A.G. Richardson	61	Mecklenburg	Boydton
26	Cumberland	Cumberland	62	Middlesex	Middlesex
27	Danville	Glenwood Magnet	63	Montgomery	Margaret Beeks
28	Dickenson	Clintwood	64	Nelson	Rockfish River
29	Dinwiddie	Midway	65	New Kent	New Kent MS
30	Essex	Tappahannock	66	Newport News	McIntosh
31	Fairfax	Beech Tree	67	Norfolk	Bay View
32	Fauquier	M.M. Pierce	68	Northampton	Kiptopeke
33	Fluvanna	Central	69	Northumberland	Northumberland
34	Franklin	Burnt Chimney	70	Nottoway	Nottoway MS
35	Frederick	Rbt. E. Aylor MS	71	Orange	Gordon-Barbour
36	Giles	Eastern	72	Page	Grove Hill

[a]All schools are public elementary schools unless designated otherwise.
[b]MS: middle school.
[c]EMHS: combined elementary, middle, and high school campus.
[d]MHS: combined middle and high school campus.
[e]Powhatan is a private K-8 school.

Appendix 1: (continued).

Number	District	School	Number	District	School
73	Patrick	Blue Ridge	90	Shenandoah	Ashby Lee
74	Petersburg	Walnut Hill	91	Smyth	Atkins
75	Pittsylvania	Stony Mill	92	Southampton	Ivor
76	Portsmouth	Churchland MS	93	Spotsylvania	Berkeley
77	Powhatan	Pocahontas	94	Stafford	Stafford
78	Prince Edward	Prince Edward	95	Suffolk	Mount Zion
79	Prince George	Harrison	96	Surry	Surry
80	Prince William	Nokesville	97	Sussex	Chambliss
81	Pulaski	Critzer	98	Tazewell	Graham
82	Rappahannock	Rappahannock Co.	99	VA Beach	Kempsville HS
83	Richmond	Richmond Co.	100	Warren	A.S. Rhodes
84	Richmond City	John B. Cary	101	Washington	Greendale
85	Salem	G.W. Carver	102	Westmoreland	Montross MS
86	Rockbridge	Central	103	Wise	Coeburn MS
87	Rockingham	Fulks Run	104	Wythe	Speedwell
88	Russell	Copper Creek	105	York	Coventry
89	Scott	Dungannon MS			

[a]All schools are public elementary schools unless designated otherwise.
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High Resolution Dune Complex Mapping for the Monitoring of Coastal Landform Change, First Landing State Park, Virginia

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ABSTRACT

First Landing State Park is located on the southern shore of the mouth of the Chesapeake Bay. The park contains a prograding shoreline and dune complex that has been steadily growing northward. Accurate three dimensional mapping of the resident coastal dune features is challenging due to the dynamic nature of the dunescape. Precise mapping within First Landing was accomplished through careful planning, employ of advanced Global Positioning System (GPS) technology, and intensive data analysis. Mapping ensued during a period of optimal satellite signal availability and strength. Data points were collected at manual intervals with a *Leica* GS50+ GPS receiver, utilizing real-time kinematic (RTK) corrections from ground control stations. Vertical data accuracies of less than 5cm were achieved. Horizontal accuracies were near 1cm. The resultant data was interpolated to create realistic contour maps, triangulated irregular networks (TINS), and raster elevation models of the study area. The methods employed may be replicated at standard time intervals for the purpose of establishing a database to maintain an inventory of dune features within First Landing. Temporal changes in this inventory may be monitored to illustrate rates of change and illuminate conditions that may require management intervention.

INTRODUCTION

First Landing State Park is located on the southern shore of the mouth of the Chesapeake Bay. It was bought by the Commonwealth of Virginia in 1933, dedicated to the citizens of the Commonwealth in 1936, and added to the National Register of Natural Landmarks in 1975. It is the most northern point on the United States East Coast where temperate and subtropical plants grow together. The park consists of cabin rentals, campgrounds, an environmental educational center, nature, hiking and biking trails. This park is one of Virginia's most popular and attracts tens of thousands of tourists per year.

Since the end of the last major glacial event, relative sea level has been rising. The term "relative" is used to indicate sea level when compared to land surface elevation. Land subsidence can result in increases in relative sea level that are much higher than the rate at which the sea itself is rising (Poag, 1999). The increase in relative sea level has inundated and eroded a significant portion of the Virginia coast. However, eroded sediments do not vanish. They are transported and deposited elsewhere. The Cape Henry coast is essentially a left-handed spit built up from sediment eroded from the beaches further south by a process called longshore drift. This current of moving sand runs into the Chesapeake Bay and is disrupted by east-west trending tidal currents. These tidal currents then redistribute the sand onto the shoreline of the Chesapeake Bay and into shoals in the Bay mouth (Figure 1). This influx of sand builds up, resulting in the northward advance of the shoreline. Over long periods of time, this erosion, transportation and redeposition of sand along Virginia's southeast coast has built up the large prograding shoreline/dune complex that is Cape Henry (Figure 2). The dunes in the Fort Story area, north of the visible dune crests, are not as visible as construction in/around the base has disrupted the natural visible pattern.

Precision mapping of areas of the shoreline and dune complex subject to these erosional and depositional forces can serve as an essential tool for coastal resource managers. This area mapped in this study was roughly rectangular portion of the backshore area on First Landing State Park between the camp store beach access walkway and next adjacent wooden walkway to the east. The northern limit of the mapped area was the shoreline at mean high water (MHW). The edge of the maritime pioneer forest served as the southern boundary. The mapped area has a series of three dune crests separated by shallow swales that deepen as one moves inland. The dunes closest to the beach, the foredunes, are sparsely vegetated with beach grass and secondary vegetation that traps "wind blown sands and cause(s) the foredune to grow vertically. . ."(Hardaway et al., 2001). In a report commissioned by the U.S. Army Corp of Engineers, W.W. Woodhouse (1978) states that, "New barrier dunes develop in this zone and the pioneer plants are usually used to build new dunes or to stabilize bare zones". The area immediately behind the foredune, the "scrub or Intermediate Zone" (Woodhouse, 1978), consists of two secondary dune crests separated by swales. Here, the vegetation is less sparse, trapping wind blown sand that acts to stabilize the area (Hardaway et al., 2001). The southern edge of the third dune begins the tree line, defined by Woodhouse (1978) as the "Forest Zone", and is populated by short, windblown trees and scrub brush. The campsites are located just beyond and, in rare cases, on top of the third dune line. Numerous trails were observed winding through the dunes to the campground areas. These trails appear to have been made by campers desiring an easy path to the beach. The creation of the trails has depleted the vegetation along their route and has destabilized the dunes and swales, creating slight trenches. While no wildlife was observed, evidence of fauna consisting of herbivore scat and crab burrows were seen scattered throughout the dunes.

MATERIALS AND METHODS

All significant aspects of a precision mapping project must be articulated before venturing into the field so that they may be performed effectively. A preliminary field survey of First Landing State Park was conducted for the purpose of delineating study area limits, data acquisition times, and mapping techniques. It was determined that

FIGURE 1. Longshore drift and accretion at First Landing State Park.

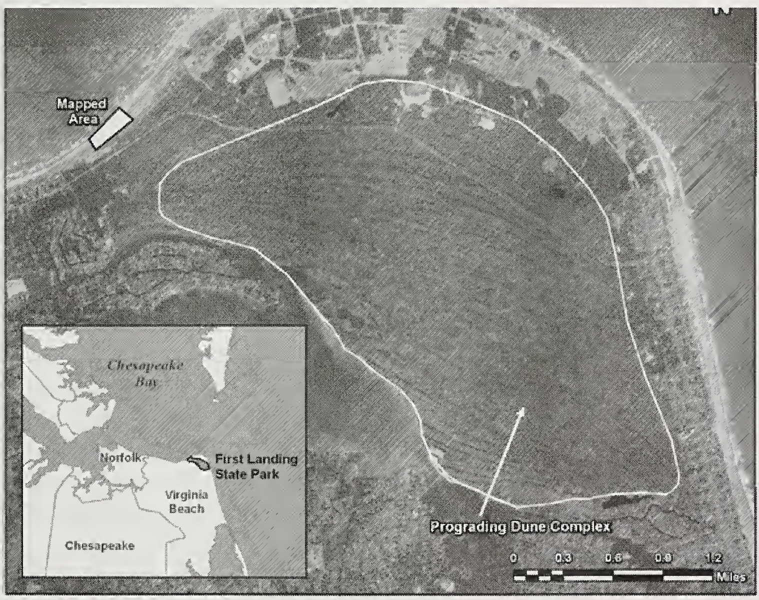

FIGURE 2. Cape Henry dune complex and First Landing State Park mapping site. Aerial Imagery © 2002 Commonwealth of Virginia.

it would be necessary to collect vertical data along three sand dune transects for use in subsequent interpolation of contour lines. In complement to these dune profiles, the capture of shoreline, berm, toeslope, vegetation line, swale, dune crest line, and foot path features was deemed critical to the creation of detailed contour and terrain maps. No significant obstructions were observed that would prevent data collection between the two beach access boardwalks lying to the east-northeast of the park's administrative center.

Two Global Positioning System (GPS) receivers were used for data acquisition. Data that did not mandate accurate vertical measurement was captured with a Trimble GeoXT GPS unit. The GeoXT receiver has sub-meter horizontal accuracy and integrates WAAS and EVEREST multi-path rejection technology for the elimination of satellite signal noise and interference. All critical elevation data were recorded with a Leica GS50+ GPS receiver. The GS50+ employs the use of a Real-Time Kinematics (RTK) system to obtain in vertical accuracies of ±5 centimeters. In the kinematic mode, corrections to the signals of the moving receiver are calculated in real-time from another, simultaneously operating base receiver fixed in a nearby position (Nickitopoulou et al., 2006).

Regardless of the RTK capabilities of the receiver, the accuracy of any GPS data is greatly dependant upon the availability and strength of satellite signals. Software programs are used to predict satellite availability, determine the best observation periods for a collection session, and visualize satellite availability. The Quick Plan mission planning software (Trimble) was used for this study. Almanac files, generated from orbiting satellites, are used with Quick Plan to determine optimal criteria for the geographic position of the study site, 36 55.16' N, 76 03.2' W. An almanac is a set of data that is used to predict satellite orbits over a moderately long period of time. Positional dilution of precision (PDOP) of the satellite data were derived from the combination of satellite signal strength data and available almanac files. Field forays were scheduled for periods of optimally high satellite availability and low PDOP.

Data collection commenced during calm weather conditions to minimize the potential effect of wave action on shoreline observations. The shoreline feature was recorded as a line type vector data feature and was taken near mid-tide in order to simulate mean sea level. Lunar cycles were determined to have a negligible effect on the mapping output and were disregarded.

Nine predetermined "control points" within the dune field were marked with survey flags and would be used to identify the locations of three dune profile transect measurements. Several feature classes and attributes were created in the Leica data logger in order to increase the speed and efficiency of the dune mapping process. These features included: swale lines, dune crest lines, toe slope base, and transect/spot elevations nodes. To ensure the most accurate vertical readings, the Leica receiver was deployed on a 7' pole attachment. This ensures sub-centimeter accuracy by automatically adjusting all readings by the exact height of the pole. This compares favorably to use of a backpack-mounted receiver for which the height of the receiver is not a constant.

The receiver was calibrated for the manually recording of horizontal and vertical (x, y, z) data nodes. Manual data entry is more time consuming than automated data logging, but allows the researcher to exercise precise control over each measurement. Nodes were recorded approximately every 20 paces in dune crest and swale lines. User

FIGURE 3. Operation of Leica GS50+ RTK GPS receiver by Jim Collins in mapping the dune field.

discretion was applied in determining if the distance was to be increased (over long evenly sloped sections) or decreased (upon major changes in slope). Vertical measurement errors caused by the depth of the sandy surface were avoided by placing the base of the Leica receiver pole gently and precisely atop the sand for each measurement (Figure 3). The path of each crest and swale line was not geometrically predetermined. The shifting nature of the dune pattern required human discretion to determine the continuity of these features. These crest and swale lines were delineated by consensus. The dune transect nodes, however, were determined in a strictly purposive manner. These profiles were recorded by a manual recording of GPS points at every major change in slope along the pre-marked transect. Node recording for each transect began at the toe of the first barrier dune and continued until the campground canopy was reached. This data was recorded entirely as a collection of nodes rather than a line feature primarily because there is no true linear topographic feature that cuts through the study area in this manner.

At the conclusion of the collection period data were immediately downloaded and reviewed on a field located laptop. The visual display of the data readings confirmed the recordings to be congruent with the mapping objective. Data from the Leica receiver was subsequently exported into ASCII text and then converted to shapefiles (ESRI). The ASCII text files were generated to ensure the display of the vertical value for each node along the swale and dune crest lines. These data were imported into Microsoft Excel as comma delimited text files in order to maintain X, Y, and Z data

columns. Each column was formatted to include numbers up to 2 decimal places. The data were then exported as a .dbf (IV) file type and then used to generate data point features in the ArcGIS 9 (ESRI) software.

All data were post-processed against the CORS (continuously operating reference station), Loyola Enterprises Chesapeake, VA base station and exported as an ESRI shapefiles. This post-processing applied a differential correction that further improved the accuracy of each reading.

These post-processed node data were interpolated to a raster grid within the ArcGIS Spatial Analyst using an ordinary kriging algorithm with a spherical variogram model. Kriging is a method for linear optimum unbiased interpolation with a minimum mean interpolation error (Theodossiou and Latinopoulos, 2006). The primary concern of the use of any interpolation technique is with the imprecision of the original data. This particular concern was eliminated by the use of precision RTK adjusted GPS data. Grid parameters were set to a fixed search radius of 150 feet, minimum acceptable value of 0 and a grid cell size of 25 feet. These parameters were chosen to allow statistical infilling of the entire project area without too much smoothing of the raw data or too much grid extrapolation beyond the control points. Surface Analysis was utilized to construct the contours from the grid. Contouring every foot with base contour set to 0 and no z factor scaling was accomplished and overlaid on the grid surface for a final contour map of the study area (Figure 4).

The 3D Analyst ArcGIS extension and ArcScene were used to create a visualization of an approximate surface of the study area. The elevation values of the interpolated raster were exaggerated to provide visible contrast within a simple three-dimensional model of the ridges and swales of the dune field (Figure 5). In addition to the production of detailed visual representations, these data allowed for the calculation of the area and volume of the study area. Approximately 40360 square meters of dune field were found to represent an above-MSL volume of 135000 cubic meters of sand. This volumetric calculation is a critical and easily replicable component of the monitoring of temporal changes in an observed dune field.

DISCUSSION

The development of increasingly accurate GPS technology allows for precision mapping of coastal topography. Accurate, localized topographic maps may be produced and utilized to support the analysis of change within the coastal zone. However, advanced technology must be combined with comprehensive human knowledge of geospatial techniques in order to be completely useful. Schubel (1981) asserts that, while changes in the coastal topography of the Chesapeake Bay typically occur on geological time scales, poor planning and conservation could reduce the functional lifespan of the Bay by half. This concept can be applied to terrestrial landforms and their accompanying bays throughout the mid-Atlantic and reinforces the need for mapping and cataloging of the coastal zone.

The data mapped in our study confirm the existence of dune patterns similar to those identified in another recent analysis performed in coastal Georgia and North Carolina. This study indicates that, "Elevational contrasts are maintained by positive relief generated by dune-building taxa and stabilization of intervening low swales by burial-intolerant woody shrubs and grass species" (Stallins and Parker, 2003). When

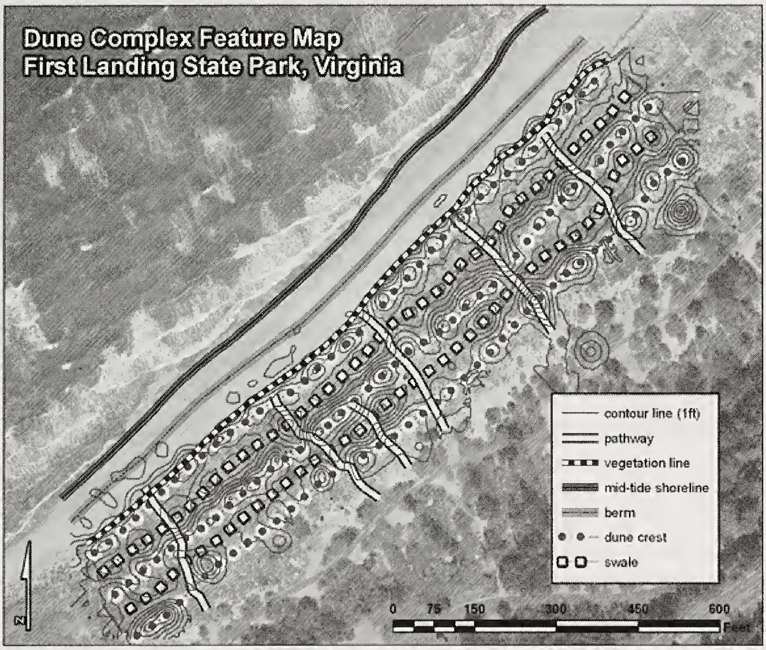

FIGURE 4. Contour and feature map. Feature widths are enlarged to enhance visibility. Aerial Imagery © 2002 Commonwealth of Virginia.

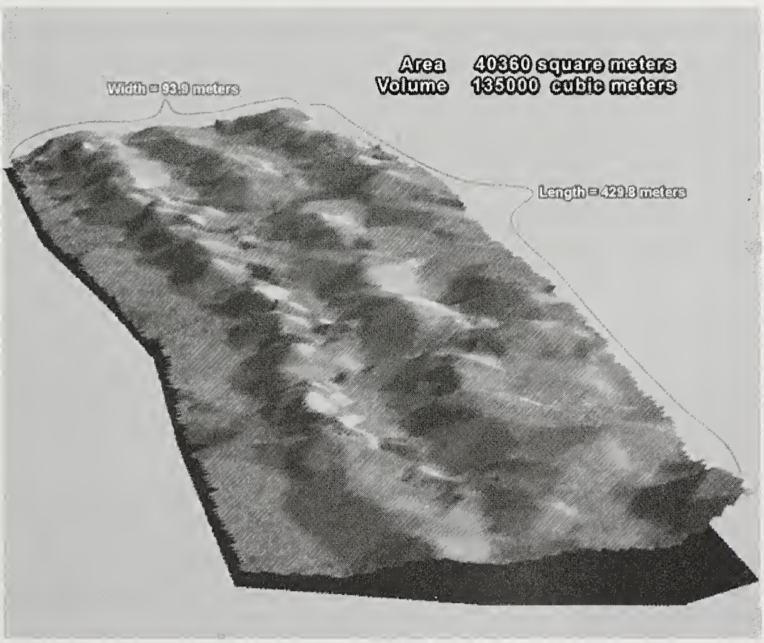

FIGURE 5. Preliminary 3-D elevation model of mapped dune field.

used properly, data such as those obtained through our study may be used to "extract" much broader conclusions about environmental change over time.

The maps resulting from this study cover a small portion of a much larger geographical area and body of knowledge. At the First Landing State Park mapping site, both visual and GIS inspections reveal a persistent pattern of shoreline advance and new dune ridge formation. Three separate dune ridges and accompanying swales were mapped between the current mid-tide shoreline and the vegetation line. The evidence suggests that the entire complex is advancing northward. The current shoreline has advanced noticeably northward from its position at the time of a 1994 aerial photograph of the study site.

The techniques used to produce the resultant digital topographic data were designed to be easily replicated. Through replication of these methods at standardized time intervals it will be possible to quantify and catalog changes in the positions of the shoreline, foredunes, dune ridges, and pioneer forest. Comparison in the position of the shoreline over time coupled with the dune elevation changes would afford an estimate of the rate at which sedimentation is taking place. By way of example, if the elevation of the newest dune has increased 6 inches, on average, over a decade, this might suggest that in 400 years this dune will have an elevation of 20 feet, while the shoreline will have advanced some 70 feet northward. It is also possible to use this estimated sedimentation/dune growth rate to construct regressive and/or predictive models of the topography. These models could provide a visualization of what the coastline may look like in the future or what it may have looked like in the past.

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An Isotropic Metric

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ABSTRACT

An isotropic metric for a black hole and a better vacuum condition $\nabla^2 V_G = 0$ are presented which yield distinct terms for the energy densities of ordinary matter and gravitational fields in the Einstein tensor ($G^{44} = -g^2(2\nabla^2 V_G + (\nabla V_G)^2)$). This model resolves an inconsistency between electromagnetism and gravity in the calculation of field energy. Resolution of this inconsistency suggests a slight modification of the Einstein equation to $gG^{\mu\nu} = 8\pi GT^{\mu\nu}$.

INTRODUCTION

One can calculate the energy in the electric field of a shell of charge two different ways, which give the same result: One can integrate the square of the electric field over all space around the shell of charge, or one can integrate the work done in moving the charges to the shell. For electromagnetism, like charges repel. So one does positive work to assemble a sphere of charge, like compressing a spring. Thus an electric field has positive energy and positive mass. For gravity, like charges attract. So one does negative work to assemble a spherical shell of mass. Therefore, gravitational fields should have negative energy and negative mass. The vector or tensor nature of the field has no significance in this calculation since the energy stored is force through distance.

Analogies between gravitational and electromagnetic fields are usually explored in the linear approximation for gravitational fields. (See, for example, Chapter 3 of the text by Ohanian and Ruffini 1994) Such expositions may recognize that in the linear approximation, the laplacian of the field should be zero in the absence of matter, and that a gravitational field should contribute a term to the energy density which has a form of the square of the gradient of the gravitational potential. (e.g. ff. p.147-148.) However, when the full equations are developed, the curvature tensor $R^{\mu\nu}$ is assumed to be zero in the absence of matter. As a result the Einstein tensor $G^{\mu\nu}$ is also zero, implying that gravitational fields have no energy density. This assumption goes back a long way.

Almost all papers on gravitational fields over the last ninety years assume that mass density is always nonnegative. For example, the Einstein tensor for the Schwarzschild metric is zero, making its fields massless. The only papers that have admitted the concept of negative mass (e.g. Cattoen and Visser, 2005; Hochberg and Visser, 1998, and Morris and Thorne, 1988) have done so as a purely theoretical tool to explore the concept of wormholes, although weaknesses in this assumption have been identified (Barcelo and Visser, 2002). This assumption of nonnegative mass is the energy conditions used for all metrics in common use. Therefore, those metrics may be incorrect.

An isotropic metric for a black hole is presented here for which $G^{\mu\nu}$ has distinct terms for ordinary matter and gravitational fields. This $G^{\mu\nu}$ is derived in the usual way from the metric tensor $g_{\mu\nu}$. When $g_{\mu\nu}$ is isotropic, one can define a gravitational

potential, and then $G^{\mu\nu}$ derived from it takes the form of a difference between the laplacian and the square of the gradient of the potential. The Einstein Tensor is a purely geometric quantity. Instead of attributing the entire $G^{\mu\nu}$ to ordinary matter, only the laplacian of the gravitational potential is attributed to ordinary matter. The remainder, which has the form of an energy density of a field is attributed to the contribution of gravitational fields. It should not be surprising that each term of $G^{\mu\nu}$ transforms properly under a lorentz transformation, because it is incidental whether each term is locally zero. An isotropic metric has the additional feature that world lines do not cross event horizons, thus avoiding interactions with regions where physical models break down.

METRIC AND EINSTEIN TENSOR

For an isotropic metric with gravitational distortion g, in the rest frame of the source of the gravitational field,

$$ds^2 = -(g_r)^2(dx^2 + dy^2 + dz^2) + dt^2/(g_t)^2 \quad . \tag{1}$$

Justification will be shown later for $g_r = g_t = g$. This metric differs from simply isotropic coordinates in that a sphere of radius r has a surface area of $4\pi g^2 r^2$ instead of $4\pi r^2$. Because the speed of light slows by a factor of g^2, the metric is *not* conformally flat, as will be shown later with the geodesics (Eq. 13).

The gravitational distortion affects momentum and energy as well as distance and time. For example, one could use a photon with a frequency matched to that of a clock in a gravitational well to carry information about the clock out of the well. Then, the gravitational distortion should affect energy the same as frequency. As a photon of energy M_γ climbs out of the gravitational potential, $g \cdot d(M_\gamma V_G) = -d(g M_\gamma)$, which yields $g = \exp(-V_G)$. Then the Einstein tensor, in spherical coordinates, derived from the isotropic metric of the length differential (Eq. 1) is:

$$G^{\mu\nu} = \begin{pmatrix} (\nabla V_G/g)^2 & 0 & 0 & 0 \\ 0 & -(\nabla V_G/rg)^2 & 0 & 0 \\ 0 & 0 & -(\nabla V_G/rg\sin\theta)^2 & 0 \\ 0 & 0 & 0 & G^{44} \end{pmatrix} \tag{2}$$

where $G^{44} = -g^2(2\nabla^2 V_G + (\nabla V_G)^2)$. From Einstein's equation, $G^{44} = 8\pi G T^{44}$, where T^{44} is the mass density. Because $V_G < 0$, $-g^2\nabla^2 V_G > 0$. This term represents mass density of ordinary matter. The term $-g^2(\nabla V_G)^2 < 0$ represents the mass density of gravitational fields. Both the gradient and laplacian are calculated with the metric scaling the coordinates in the usual manner.

If one admits azimuthal as well as radial variation for g, then G^{44} still retains the same form. When expanded,

$$G^{44}=\left(2\frac{g,_{rr}}{g}+\frac{4g,_r}{rg}-\left(\frac{g,_r}{g}\right)^2\right)+\frac{1}{r^2}\left(2\frac{g,_{\theta\theta}}{g}+2\frac{g,_\theta}{g}\cot\theta-\left(\frac{g,_\theta}{g}\right)^2\right). \qquad (3)$$

A comma indicates partial derivatives with respect to the coordinates that follow it. The squared terms are the square of the gradient of the potential. All other terms are the laplacian of the potential.

MASS RECONCILIATION

The negative mass of the gravitational fields inferred by analogy with electromagnetic fields should be quantified. Suppose one attempts such a calculation, to determine the form for the gravitational distortion g in this model. In a vacuum, $\nabla^2 V_G = 0$, which is

$$2\frac{g,_{rr}}{g}+\frac{4g,_r}{rg}=0 \quad . \qquad (4)$$

With $g = 1$ and $V_G = -GM/r$ for large r, the solution to this equation is

$$g=1+\frac{GM}{r} \qquad (5)$$

where M is the mass of the shell of matter. The remaining term in G^{44} is the mass of the gravitational fields. With spherical symmetry,

$$G^{44}=-g^2\left(\nabla V_G\right)^2=-\left(\frac{g,_r}{g}\right)^2 \quad . \qquad (6)$$

Total mass of the gravitational fields

$$M_G=2\int_{r=r_0}^{\infty}\frac{G^{44}4\pi r^2 dr}{8\pi G}=\frac{1}{G}\int_{r=r_0}^{\infty}G^{44}r^2 dr\,. \qquad (7)$$

If the energy of the gravitational fields is that which is released in assembling the shell

of mass M, then $M_G = MV_G = -M\ln g$, in analogy with assembling a shell of electric charge. When one equates these two calculations of the mass,

$$-GM\ln g = -\int_{r=r_0}^{\infty}\left(\frac{g_{,r}}{g}\right)^2 r^2 dr \ . \tag{8}$$

$$\frac{-GMdr}{r^2} = \frac{dg}{g}. \qquad \frac{GM}{r} = \ln g = -V_G\,. \tag{9}$$

This result does not satisfy the vacuum condition $\nabla^2 V_G = 0$. Apparently, the problem is over defined.

To solve this paradox, one might allow the distortion for the time coordinate, g_t, to differ from that for the space coordinate, g_r, and apply the vacuum condition only to g_r. With this substitution, G^{44} retains the desired form, $G^{44} = -g_t^2(2\nabla^2 V_G + (\nabla V_G)^2)$, and g_t appears only as a scaling factor, and not in the operators on V_G. If one admits further anisotropy, then $\nabla^2 V_G$ and $(\nabla V_G)^2$ no longer appear as distinct terms in any components of $G^{\mu\nu}$. As shown above, $g_r = 1+GM/r$ to satisfy the vacuum condition. Then equating the two ways of calculating mass results in $g_t^2 = g_r^3$. It is reasonable to conclude that instead of $G^{\mu\nu} = 8\pi GT^{\mu\nu}$, the Einstein Equation should be

$$gG^{\mu\nu} = 8\pi GT^{\mu\nu}\,. \tag{10}$$

The left side of this equation retains its tensor properties because g is a scalar. This modification conforms with the scaling of energy by the distortion. As a bonus, because mass reconciliation then yields $g_t = g_r$, both g_t and g_r satisfy the vacuum condition. For the rest of this paper, $g_t = g_r = g$.

GEOMETRY NEAR A BLACK HOLE

As one descends into this black hole with isotropic gravitational distortion $g = 1+GM/r$, it becomes increasingly self similar, since both M and r scale the same way with the gravitational distortion. Locally, the circumference asymptotically approaches $2\pi GM$, and the remaining distance to the event horizon asymptotically approaches GM.

To calculate the geodesics, one integrates the local time for a photon to travel between two points, factors out the constant g^2c, and applies the Euler-Lagrange equations to the integrand.

$$\Delta T = \int \frac{dt}{g} = \frac{1}{g^2 c} \int g \sqrt{\left((r_{,\theta})^2 + r^2 \right)} d\theta \quad . \tag{11}$$

The resulting geodesics are given by:

$$0 = r^2 r_{,\theta\theta} - 2r(r_{,\theta})^2 - r^3 - \frac{g_{,r}}{g}\left((r_{,\theta})^2 + r^2\right)^2 . \tag{12}$$

For $g = 1 + GM/r$,

$$r_{,\theta\theta} = \frac{2(r_{,\theta})^2}{r} + r - \frac{GM}{r(r+GM)}\left((r_{,\theta})^2 + r^2\right)^2 . \tag{13}$$

The right most term distinguishes these geodesics from those for flat space. It deflects the path of light toward the gravitational potential. The time for a photon to reach the event horizon at the center is infinite whether measured by an outside observer:

$$\Delta T = \frac{1}{g^2 c} \int_{r_1}^{r_2} g ds \approx \frac{GM}{g^2 c} \log \frac{r_2}{r_1} \tag{14}$$

or in a frame descending into the gravitational well:

$$\Delta T = \frac{1}{g^2 c} \int_{r_1}^{r_2} g^2 ds \approx \frac{GM}{g^2 c}\left(\frac{1}{r_2} - \frac{1}{r_1}\right). \tag{15}$$

A MASSLESS METRIC

For purposes of comparison, the following gravitational distortion describes a distribution of matter contrived to exactly cancel the negative mass of gravitational fields everywhere outside the event horizon:

$$g = \frac{r}{r - GM} = \frac{1}{1 - GM / r} . \tag{16}$$

Although $G^{44} = 0$ for this metric, G^{11}, G^{22}, and G^{33} are all nonzero. So, this $G^{\mu\nu}$ is not the same as for flat space.

An event horizon resides at $r = GM$. Substitution of g into the equations for time of travel (Eq. 14, 15) shows that objects still do not cross the event horizon. At a radius $2GM$, this metric has a waist, where the circumference is a minimum. Circumference $l_C = 2\pi rg = 2\pi r^2/(r\text{-}GM)$ which has a minimum value of $8\pi GM$. The total distance between two points at different depths

$$s = \int \frac{rdr}{r - GM} = \int_{r_1}^{r_2} \left(1 + \frac{GM}{r - GM} \right) dr = \left(r_2 - r_1 \right) + \log \left(\frac{r_2 - GM}{r_1 - GM} \right) . \tag{17}$$

Putting $r_1 = 2GM$ at the waist and r_2 inside the waist shows that the circumference grows exponentially with depth:

$$s \approx \log \left(\frac{r_2}{GM} - 1 \right) \tag{18}$$

$$l_c = \frac{2\pi r_2^{\,2}}{r_2 - GM} \approx \frac{2\pi GMe^{2s}}{e^s - 1} \approx 2\pi GMe^s . \tag{19}$$

Thus, the distribution of mass makes the space more expansive there than it would be if the matter were absent. One might interpret matter as an excess of volume within a surface area.

CONCLUSIONS AND IMPLICATIONS

Not only does an isotropic metric result in gravitational fields with negative mass, as one should expect, it offers a number of other advantages over the Schwarzschild metric. As shown above, an isotropic metric results in a very symmetric form for the Einstein tensor, with distinct terms for ordinary mass and gravitational fields. Objects do not cross event horizons. A large amount of free energy available to objects falling in the halo of a black hole might nucleate cosmoses. For example, the massless metric just shown illustrates how the presence of an energy density induces expansion. Since this metric is isotropic, it can accommodate the nucleation of isotropically expanding cosmoses in the halo of a black hole in a way that the Schwarzschild metric cannot. An isotropic metric also terminates electromagnetic field lines in a way that the

Schwarzschild metric and Kerr metrics cannot: Deep enough into the halo of the black hole, the circumference and surface area increase, thus causing electromagnetic field strengths decrease. Projected out, it appears that a charge density resides in the halo of a charged black hole. The termination of field lines provides cutoffs for fields, limits field energies, and might accommodate general relativistic models for the masses of the electron, muon, and tauon.

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JEFFRESS RESEARCH GRANT AWARDS

The Allocations Committee of the Thomas F. and Kate Miller Jeffress Memorial Trust has announced the award of Jeffress Research Grants to the institutions listed below to support the research of the investigator whose name is given. The Jeffress Trust, established in 1981 under the will of Robert M. Jeffress, a business executive and philanthropist of Richmond, supports research in chemical, medical and other natural sciences through grants to non-profit research and educational institutions in the Commonwealth of Virginia. The Jeffress Research Grants being announced here have been awarded in 2005.

The Jeffress Memorial Trust is administered by Bank of America. Additional information about the program of the Trust may be obtained by writing to: Richard B. Brandt, Ph.D., Advisor, Thomas F. and Kate Miller Jeffress Memorial Trust, Bank of America, Private Bank, P. 0. Box 26688, Richmond, VA 23261-6688. An unofficial website is listed under Grants and Awards, www.vacadsci.org/grants.htm.

Julio C. Alvarez. Virginia Commonwealth University. Development of Electrochemical Biosensors in Plastic Microfluidic Chips. $10,000. (one year renewal).

Rebecca Ambers. Sweet Briar College. The lnfleucnce of Clay Mineralogy and Mineral Cements on Stream Channel Erodability. $10,000. (one year renewal).

Joseph D. Ametepe. Hollins University. Studying and Using Discharges from a Novel High-Energy Ultraviolet Light Source for Destroying Viruses and Bacteria in Drinking Water. $10,000. (one year renewal).

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Ancha Baranova, George Mason University. Melanin Biosynthesis in Adipocytes: Cross-talk Between Energy Balance and Pigmentation Control. $23,000. (one year).

Stephen F. Baron, Bridgewater College. Regulation of Excellular Polyhydroxalkanoate Depolymerase Synthesis in Streptomyces spp.5A. $10,000. (one year renewal).

Craig Bayse, Old Dominion University. Understanding the Role of Se...N, 0 Interactions in the Activity of Selenoproteins and their Mimics: A Theoretical Study. $10,000. (one year renewal).

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Joshua Burk, College of William and Mary. Posterior Parietal Cortical Acetylcholine and Attention. $24,000. (one year).

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